California Inspection and Maintenance Review Committee

Smog Check II Evaluation

Part II: Overview of Vehicle Emissions

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1. Introduction

This chapter provides a summary of (1) information on the nature and distribution of vehicle emissions in the on-road vehicle fleet, and (2) analysis of vehicle emissions issues that have relevance for Smog Check policy.

2. Emissions Concepts Used in Later Sections

2.1. "Excess," "Reducible," and "Repairable" Emissions

Regulators and emissions researchers generally classify vehicle emissions into categories that reflect the extent to which they can potentially be reduced by repair. Cars that fail an emissions test are generally expected to have the potential for emissions reductions due to repair. Vehicles fail an emissions test if their emissions are above pre-determined levels known as "cut points" or "failure standards." Emissions above the cut points are generally referred to as excess, repairable, or reducible emissions. Note, however, that many vehicles' emissions are intrinsically variable from test to test (emissions variability is discussed in more detail in Section 7).

2.2. Fuel-Based vs. Travel-Based Emissions Tests

Emissions tests can be divided into those that measure emissions in grams per gallon of fuel consumed (fuel-based tests) and in grams per mile traveled (travel-based tests). The IM240, used in many centralized I/M programs, and the Federal Test Procedure (FTP), which is used to certify that new vehicles meet federal and California emissions standards, are travel-based emissions tests. Emissions from these tests are generally reported in grams per mile (g/mile). The ASM emissions test used in California's Smog Check program, and remote sensing devices are fuel-based tests. Emissions from these tests are generally reported in concentration units (parts per million (ppm) or percent (%) where 1% = 10,000 ppm) or in grams of emissions per gallon of fuel consumed (g/gal).

2.2.1. Converting between fuel-based and travel-based measurements

Emissions regulations are based on travel-based tests, so it is useful to be able to convert between the two types of measurements. There are two ways to estimate travel-based emissions from fuel-based emissions. First, if the fuel economy of a vehicle is known, one can directly convert from fuel-based emissions to travel-based emissions by multiplying emissions in grams per gallon times the fuel economy in gallons per mile. However, the exact fuel economy of any particular vehicle at a particular moment in time is uncertain, because it is dependent on the type of vehicle, the condition it is in, and the load its engine is under when tested. Nonetheless, one can use the reported fuel economy of the vehicle on the FTP, or the fleet-weighted average fuel economy, for vehicles in a given model year as an estimate for this calculation.

Second, if data for a large group of randomly selected cars that has been tested on two different tests, say the ASM and the FTP, one can use a statistical technique called regression analysis to develop a set of equations relating ASM emissions to FTP emissions. Under a contract with BAR, the Eastern Research Group (ERG) has developed such a set of equations. The ERG model uses vehicle-specific factors, such as age, weight, whether it has a carburetor or is fuel injected, and whether it is a passenger car or a truck, to predict FTP emissions from ASM measurements. Although the conversion is not exact, this method is useful for estimating average FTP emissions of large samples of vehicles. However, ERG stresses that it is not suitable for accurately predicting FTP emissions of a single vehicle.

2.3. Tailpipe vs. Non-Tailpipe Emissions

NOx and CO emissions are produced only during fuel combustion and therefore generally are emitted only from the tailpipe of a vehicle. HC emissions also come out of the tailpipe when they are incompletely burned in the engine and not destroyed by the catalytic converter. However, the hydrocarbons of which gasoline is composed can also leak or evaporate from the fuel storage and delivery systems of cars. These emissions are generally referred to as non-tailpipe, or evaporative, emissions.

There is a great deal of uncertainty about what portion of vehicle HC emissions comes from non-tailpipe sources. A recent peer-reviewed study concluded that the non-tailpipe fraction could range from as low as 15 percent to more than 50 percent and that current data are insufficient to resolve the issue.[1]

California's Smog Check program currently has the potential to affect non-tailpipe emissions mainly through the gas cap pressure test. However, other sources of non-tailpipe emissions, such as liquid leaks and problems with automobile evaporative emissions-control systems are likely much larger sources of non-tailpipe HC. The IMRC evaluation does not include non-tailpipe HC emissions in its Smog Check evaluation due to lack of appropriate data. However, the IMRC plans to examine this issue further in the coming months. This report focuses only on tailpipe emissions.

2.4. Dealing with Uncertainty

The following sections of this report present data on many aspects of vehicle emissions, including the number of vehicles on the road, average emissions for each model year, and the distribution of emissions among vehicles. These results are estimates of what is going on in the real world, and they are subject to uncertainties. These uncertainties may be small in some cases and large in others. Several factors create uncertainty in estimates of real-world vehicle emissions:

- ***Sample Bias.*** Millions of vehicles are on the road in California. Researchers estimate their emissions characteristics by sampling a small portion of them. But sampling always entails the possibility that the sample might not be representative of the whole population. For example, high-emitting vehicles might be underrepresented in a sample of vehicles relative to their presence in the vehicle fleet as a whole.

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[1] Pierson, W. R., D. E. Schorran, et al. (1999) "Assessment of Nontailpipe Hydrocarbon Emissions from Motor Vehicles", *Journal of the Air and Waste Management Association*, vol. 49, pp. 498-519, May 1999.

- ***Artificial Test Conditions.*** In I/M programs, vehicle emissions are measured using specific emissions tests such as the ASM or the IM240. These tests include carefully controlled driving conditions. However, the driving conditions on the test will not represent the way many cars are actually driven. For example, the ASM test includes only a steady cruise and the IM240 test does not include very high accelerations. Emissions change with driving conditions, so variation between test conditions and real driving can cause errors in fleet emissions estimates.[2]
- ***Fleet Turnover.*** The vehicle fleet is constantly changing, with older cars being totaled or scrapped, new cars entering the fleet, and people moving in and out of an area. The fleet measured today differs from the way the fleet will look next week or next month.

Despite these uncertainties, some estimates have a relatively high level of reliability. For example, the IMRC's data show that a small number of cars account for most pollution. This result is seen over and over again in vehicle emissions studies. But these general observations are qualitative rather than offering numerical precision. It is more difficult to say with certainty *exactly* what percentage of cars accounts for what percentage of total emissions.

For example, whether the dirtiest 10 percent of vehicles account for 40 percent of HC emissions or 50 percent (numbers in this range have been seen around the country) will change from time to time and place to place. The emission distribution will change because the makeup of the vehicle fleet changes with location and time and also because of the uncertainties in the methods used to measure the fleet. Thus, one may be quite certain of a qualitative result, but less certain of exact numerical values.

3. Older Vehicles Have Higher Emissions on Average

Figures 1a and 1b show the distribution of average HC, CO, and NOx emissions by model year, based on random roadside ASM test data collected by BAR. These data are collected by giving randomly selected cars a Smog Check at a roadside pullover site. BAR collected about 27,000 roadside measurements at dozens of Enhanced area sites between February 1997 and October 1999.[3] The top chart presents the ASM concentration measurements for all three pollutants while the bottom chart presents the same data converted to FTP equivalents using the ERG conversion equation discussed earlier. As noted earlier, these conversions are only approximate. However, the results

[2] Note also that the ASM and IM240 do not include "cold start" emissions, which are higher levels of emissions that occur for a few minutes after a car is first started and before it has warmed up (though Smog Check is not intended to have a major effect on cold start emissions). Remote sensors, which measure emissions of vehicles as they drive on the road, can be used to estimate fleet emissions under actual driving conditions.

[3] These charts are based on a subset of the data collected after January 1, 1998 and also exclude any vehicle that had an Enhanced Smog Check *before* being measured at the roadside. These selection conditions were used so that the data would most closely represent the vehicle fleet as it appeared shortly before the start of the Enhanced Program, but still include sufficient vehicles in each model year to achieve statistically sound results.

displayed here follow the same pattern seen in all emissions measurements of a broad range of vehicles. Note also that:

- CO emissions should be read from the right axis scale rather than the left. The separate scale for CO is necessary because CO emissions span a much larger range than HC and NOx emissions.
- On the ASM test, HC and NOx emissions are reported in parts per million (ppm), while CO emissions are reported in percent (1% = 10,000 ppm).
- FTP emissions of all pollutants are reported in grams per mile (g/mile).

Note the following in these graphs:

- Average emissions are much higher for older vehicles for all three pollutants.
- Mass emissions of HC and CO are much higher than NOx for older vehicles. However, emissions of all three pollutants are starting to converge for newer vehicles. Figure 1c zooms in on FTP emissions of newer vehicles. As the graph shows, average HC emissions are lower than average NOx emissions for newer vehicles. Note that all three pollutants are plotted against the left axis scale in this graph.

For comparison, Table 1 displays California's new-vehicle FTP certification standards for passenger cars for selected model years. These standards have become much more stringent for more recent model years. Table 2 displays average ASM and FTP emissions for the fleet as a whole. Based on the time period in which the roadside data were collected, these values roughly represent average fleet emissions in late 1998. These values were estimated by calculating average emissions by model year from the roadside data and then weighting these data by the estimated *travel fraction* of the vehicles in each model year. The travel fraction is the percentage of total miles traveled accounted for by a given model year of vehicles. For each model year, total miles traveled is estimated by taking the product of the estimated number of vehicles on the road from a given model year, and the estimated average miles per year traveled by vehicles in that model year.

Figure 1a. Average ASM Test Emissions by Model Year

BAR Roadside Test Data

HC and NOx plotted on left axis scale; CO plotted on right axis scale

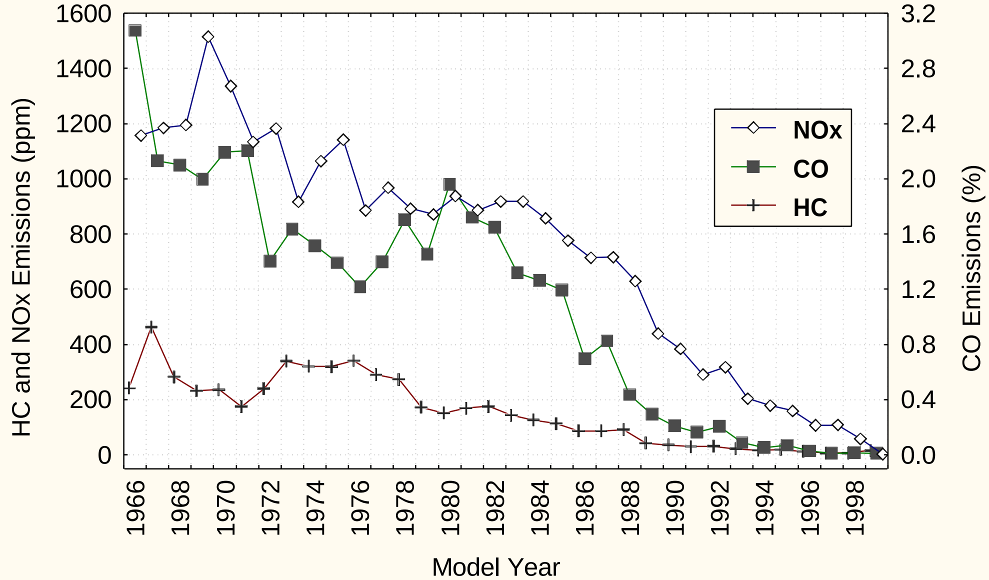


Figure 1b. Average FTP Emissions by Model Year

BAR Roadside ASM Test Data Converted to FTP Equivalents

HC and NOx plotted on left axis scale; CO plotted on right axis scale

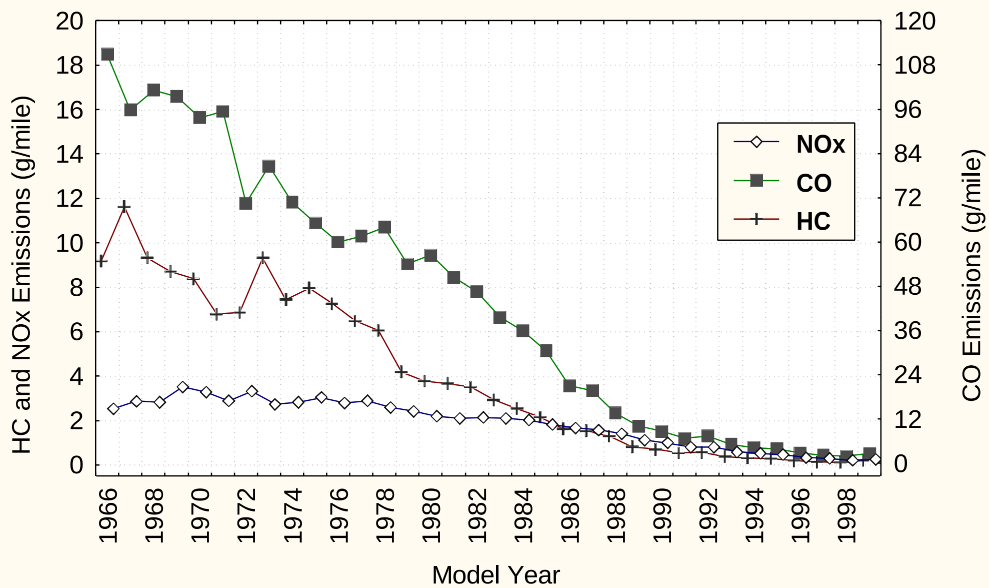
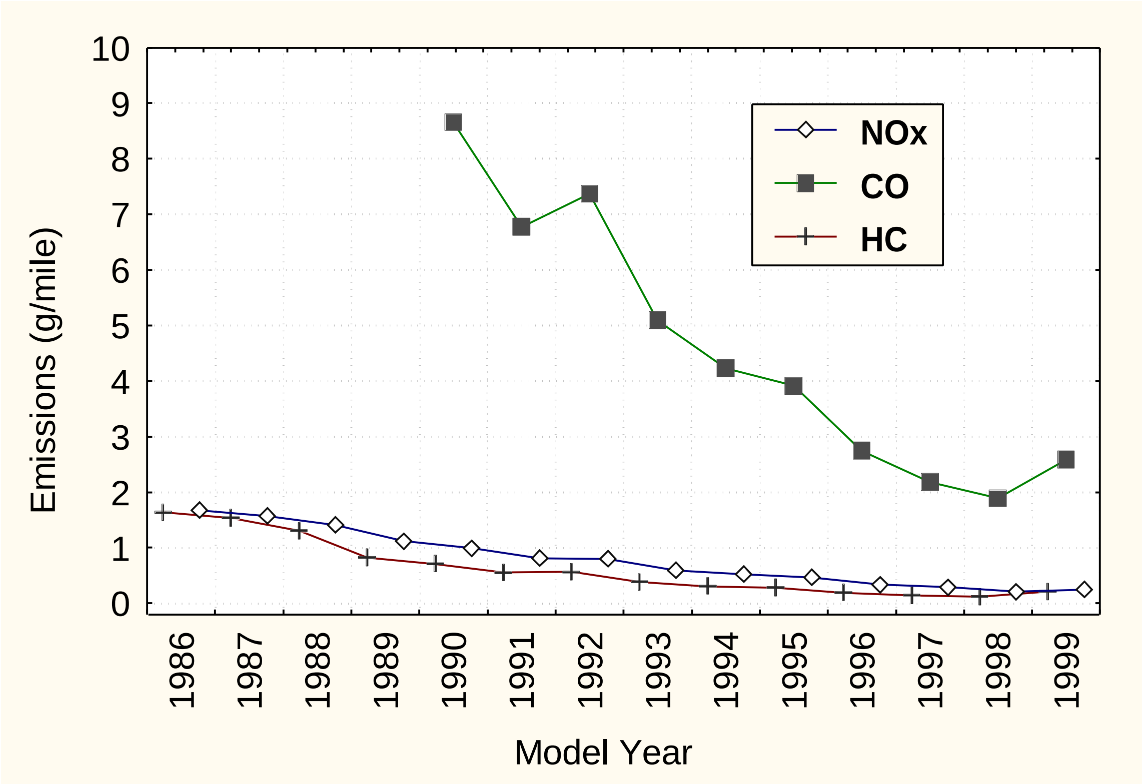


Figure 1c. Blowup of Average FTP Emissions by Model Year for Newer Vehicles



The travel fraction of each model year changes with time for two reasons. First, the number of vehicles from a given model year decreases with time as vehicles are retired. Second, older vehicles travel fewer miles, on average, than newer ones. Thus, it is important to apply a travel fraction appropriate to the time period in which emissions are estimated. Calculations for this report use a travel fraction calculator (TFC) developed by Sonoma Technology under contract with BAR.[4]

[4] The data for the travel fraction calculator (TFC) come from three sources: vehicle registration data, changes in vehicle odometer readings between Smog Checks, and new vehicle sales data. The IMRC has not evaluated the data or methodology that go into the TFC. However, it is important to note that estimates of the number of vehicles on the road and the number of miles they travel each year are subject to uncertainties for several reasons. Some vehicles are unregistered and some are scrapped or totaled without notification to DMV. Estimates of miles traveled are based on odometer readings taken at Smog Check stations. These are subject to potential data entry errors – the data may be entered haphazardly or not at all by some stations. In addition, a change in economic conditions can affect the rate at which motorists replace their vehicles.

Table 1. California New-Vehicle FTP Certification Standards for Passenger Cars

Model Year	HC	CO	NOx
1966-69	8.90	69.00	4.30
1970	6.40	61.00	4.20
1971	5.30	60.00	4.00
1972	3.20	39.00	3.20
1973	3.20	39.00	3.00
1974	3.20	39.00	2.00
1975-76	0.90	9.00	2.00
1977-79	0.41	9.00	1.50
1980	0.41	9.00	1.00
1981-88	0.41	7.00	0.70
1989	0.41	7.00	0.55
1990	0.41	7.00	0.42
1991-92	0.41	7.00	0.40
1993	0.33	5.56	0.40
1994	0.28	4.12	0.40
1995-	0.25	3.40	0.40
LEV[5]	0.08	3.40	0.20
ULEV	0.04	1.70	0.20

Source: California Air Resources Board

Table 2. Estimated Fleet Average ASM and FTP Emissions in Late 1998

Pollutant	ASM	FTP (g/mile)
HC	54 ppm	1.1
NOx	377 ppm	1.0
CO	0.4 %	14.0

[5] LEV stands for "Low Emission Vehicle" and ULEV stands for "Ultra-Low Emission Vehicle". Beginning in 1997, and each year thereafter, a steadily increasing percentage of new vehicles must meet LEV and ULEV certification standards.

4. The Vehicle Fleet Is Dominated by Newer Vehicles

Newer vehicles account for most of the vehicles on the road and an even greater fraction of total vehicle miles traveled. Table 3 displays an estimate of the distribution of the vehicle fleet by model year as of January 2000 based on the BAR TFC.

Table 3. Estimated Distribution of the Vehicle Fleet by Model Year Range

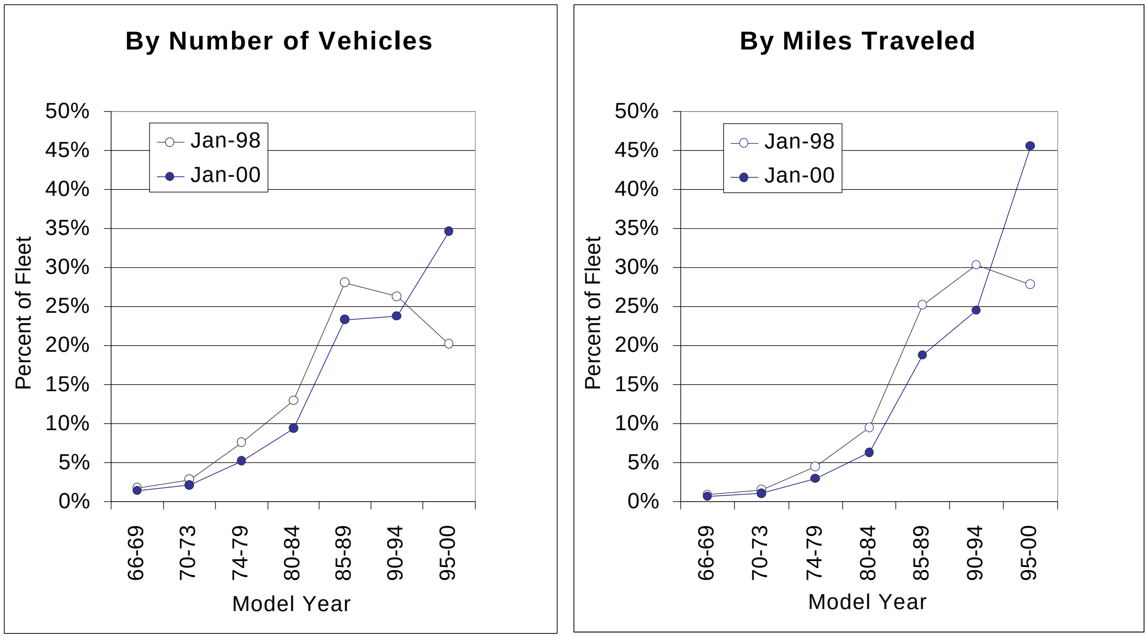
Model Year Group	Percent of Vehicles	Percent of Miles Traveled
66-69	1%	1%
70-73	2%	1%
74-79	5%	3%
80-84	9%	6%
85-89	23%	19%
90-94	24%	25%
95-00	35%	46%

Figure 2 displays an estimate of how the vehicle fleet changes with time. The figure shows the estimated composition of the vehicle fleet in January 1998 and January 2000 based on the BAR TFC. Note how older vehicles leave the fleet and newer vehicles enter the fleet. Note also that the newest model year group, 95-00, includes more model years in January 2000 than in January 1998, because there were no 1999 or 2000 model year cars on the road in January 1998. That is why the plot for the January 2000 time period rises so steeply into the 95-00 model year group.

As noted above, these fleet model year and mileage distributions are estimates based on imperfect data. Uncertainty in the size and mileage of the vehicle fleet is important because it can have a substantial effect on estimates of the average vehicle emission rate. For example, a change of plus or minus 10 percent in the estimated travel fraction of pre-1986 vehicles would change average fleet emissions by roughly plus or minus six percent for HC and CO and four percent for NOx.

As another example, if high emissions are correlated with lower vehicle reliability, high emitters might travel less than other vehicles. But travel fraction calculations typically use the same average miles traveled for all vehicles in a given model year. If, for example, the highest-emitting 10 percent of vehicles actually travel, on average, 20 percent fewer miles per year than other vehicles in the same model year, then estimated average emissions would drop by roughly ten percent for HC and CO and roughly six percent for NOx.

Figure 2. Estimated Distribution of the Vehicle Fleet by Number of Vehicles and by Miles Traveled



5. More Recent Vehicle Models Start Cleaner and Stay Cleaner Longer

Older cars have higher average emissions for two reasons. First, average emissions of a fleet of vehicles increase as the vehicles age due to wear and tear. Second, due to both more stringent new-car emissions standards and more robust design and construction, more recent models start out cleaner and deteriorate more slowly than vehicles built years ago. As a result, one can expect cars built in the 1990s to have lower emissions when they are, say, 10 or 15 years old, than the 10- or 15-year old cars on the road today.

Figures 3a, 3b and 3c show these effects. The graphs display IM240 test data for CO, HC, and NOx, respectively, from the Colorado I/M program.[6] Each line on the graph represents the emissions of one model year, and each point on a given line represents that model year at different ages. The lowest line in the CO graph (the line with the open triangle point markers), for example, represents the 1995 model year. The left-most point on the line is the 1995 model year in calendar year 1995. The right-most point on the line is the 1995 model year in calendar year 1999, that is, at four years of age. Thus, for each model year, the graph shows emissions with increasing age from left to right The graph shows emissions generally increasing with age until vehicles are more than about 10 or

[6] McClintock, P. (1999) "Options for Future Changes to I/M Programs", presentation to the Regional Air Quality CO Maintenance Plan Subcommittee, Denver, Colorado. Data are from the first quarter of each calendar year and include only initial tests of vehicles that waited 5 minutes or less in line before being tested.

11 years old. At this age, emissions appear to flatten out or even drop a bit, possibly due to the highest emitters leaving the fleet at a faster rate than the average vehicle from that model year and/or to reductions caused by I/M.

Following up the chart vertically, one observes different model years at the same age. For example, looking at four-year-old vehicles, the bottommost point at four years of age is the 1995 model year. Moving up the chart at a constant age of four years, one next comes to the 1994 model year and so on back to the 1991 model year. Vehicles built more recently, say the 1995 or 1994 model years, have lower emissions at four years of age than vehicles built in 1991 or 1992. This is true for almost all age-model year combinations. Thus, one can conclude that newer-technology vehicles start out cleaner and stay cleaner than older-technology vehicles.

Figure 3a. IM240 CO Emissions for 1982-1995 Passenger Cars in the Colorado I/M Program

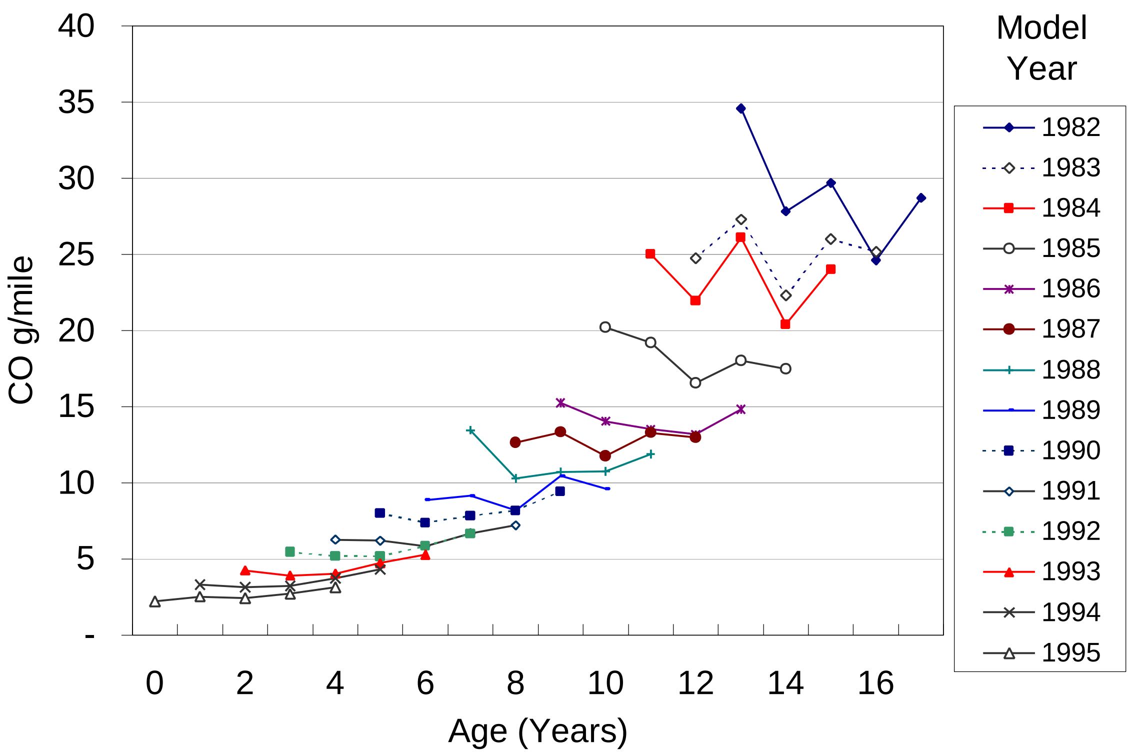


Figure 3b. IM240 HC Emissions for 1982-1995 Passenger Cars; Colorado I/M Program

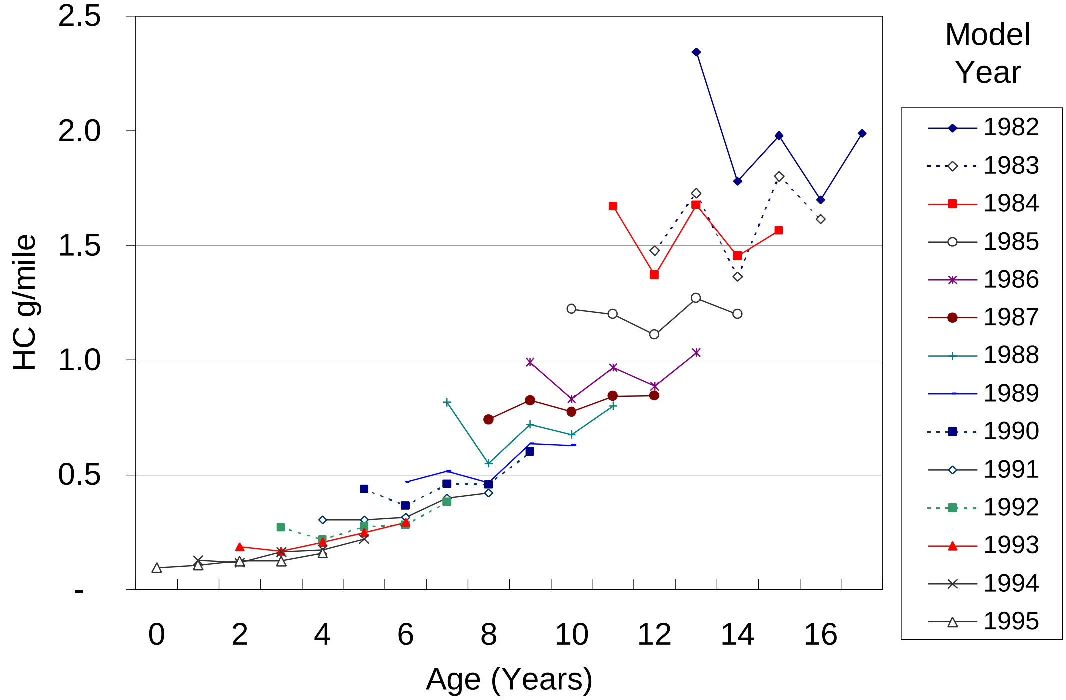
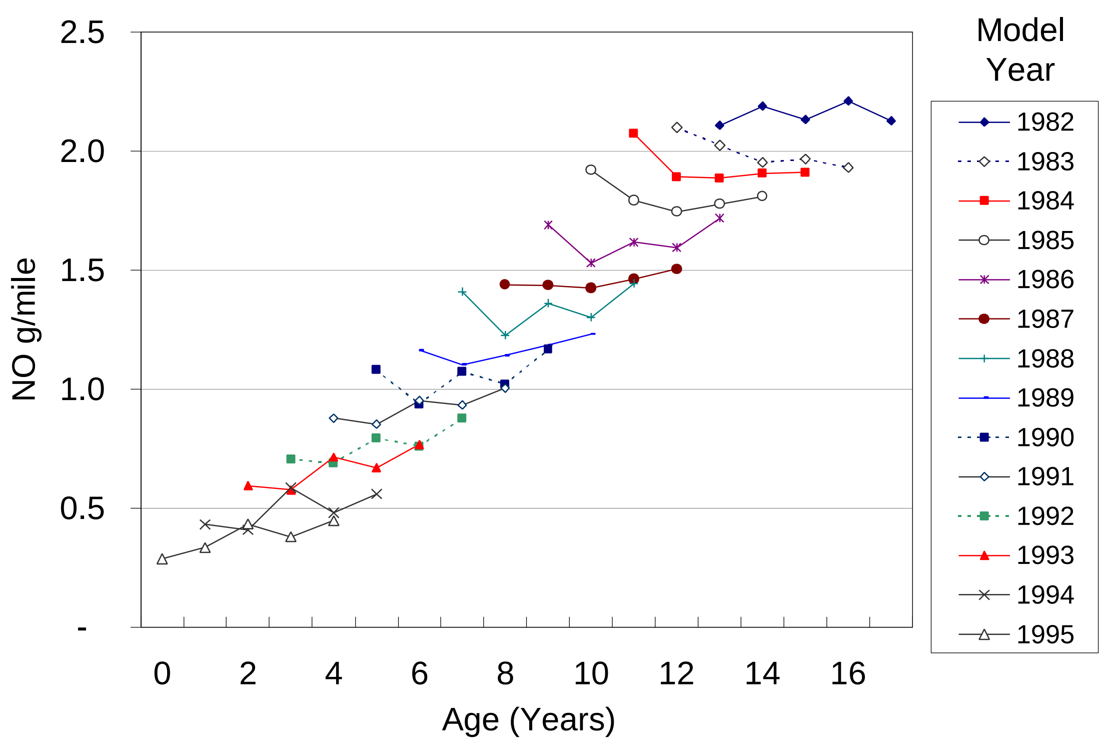


Figure 3c. IM240 NOx Emissions for 1982-1995 Passenger Cars; Colorado I/M Program



6. Emissions Vary Substantially for the Fleet as a Whole and within each Model Year

Figures 4a, 4b and 4c show the distribution of HC, CO, and NOx emissions, respectively. The vertical bars show the percent of vehicles in the fleet with emissions within the range marked under the bar on the horizontal axis. For example, looking at the leftmost bar in the graph for HC, one can see that roughly 57 percent of vehicles have emissions between zero and 50 ppm. Once again, the data for these charts come from the random roadside pullover ASM test data collected by BAR. The figure shows:

- Emissions are skewed, with most cars having relatively low emissions and some cars having extremely high emissions. For example, about 75 percent of cars have HC emissions less than 100 ppm, but about 1 percent of cars have emissions greater than 1000 ppm. To put this in the context of program failure cut points, the median HC cut point for early 1990s vehicles is about 90 ppm while the median failure cut point for early 1980s vehicles is about 120 ppm.
- NOx emissions are somewhat less skewed than HC and CO emissions.

Emissions vary over a wide range not only for the fleet as a whole, but also within each model year. Figure 5 displays the distribution of HC emissions for four different vehicle model years. Note the following:

- Almost all newer vehicles (as represented here by the 1992 model year) have low emissions. Progressively older vehicles are more likely to have high emissions.
- Even though older vehicles are more likely to have high emissions, many vehicles from the 1970s and 1980s have very low emissions.

Figure 4a. Distribution of Emissions of HC Emissions in the Vehicle Fleet

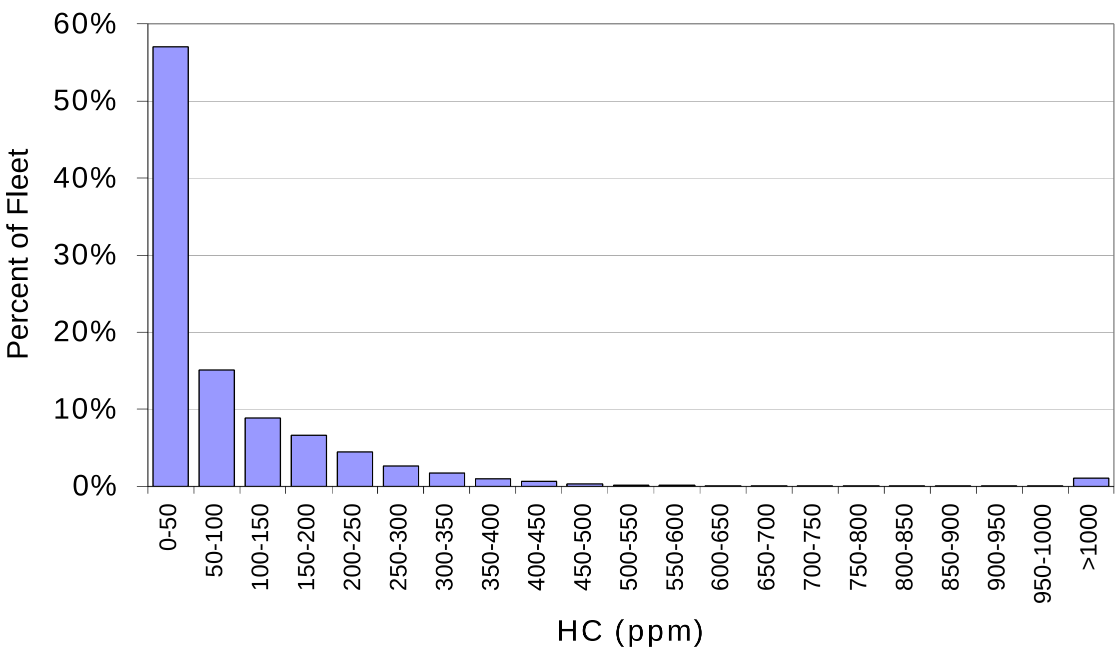


Figure 4b. Distribution of Emissions of CO Emissions in the Vehicle Fleet

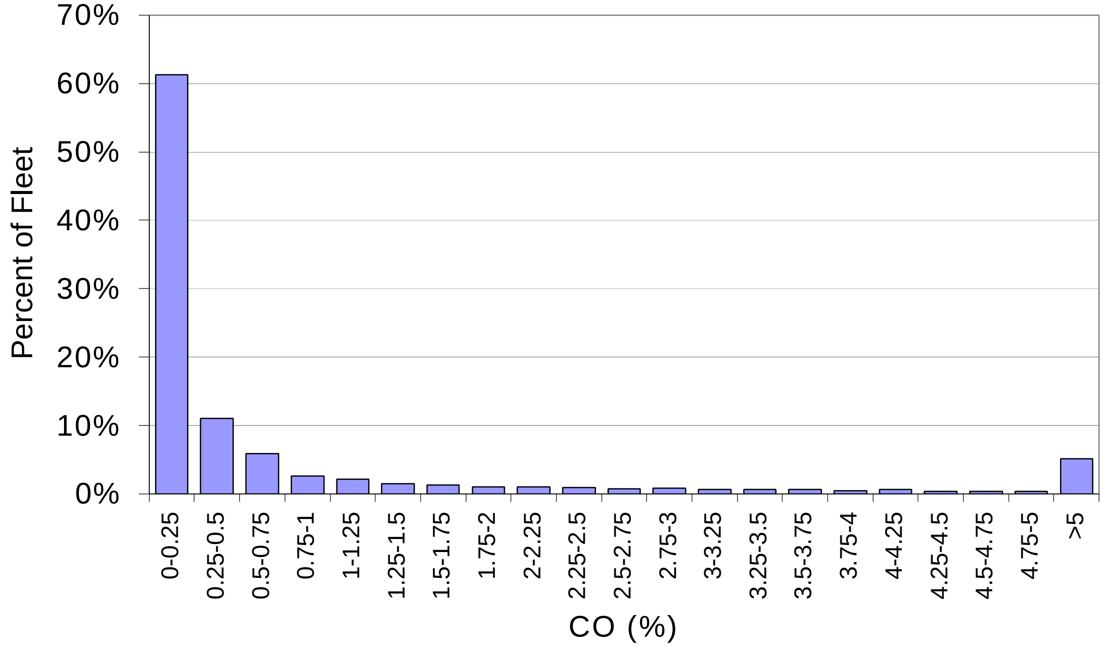


Figure 4c. Distribution of Emissions of NOx Emissions in the Vehicle Fleet

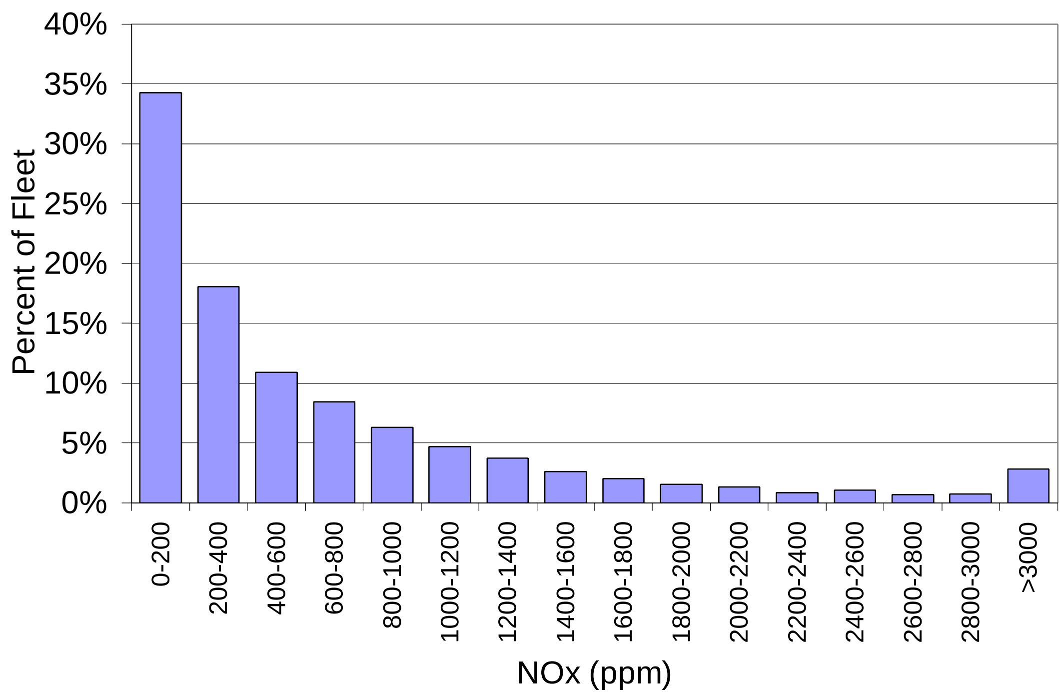
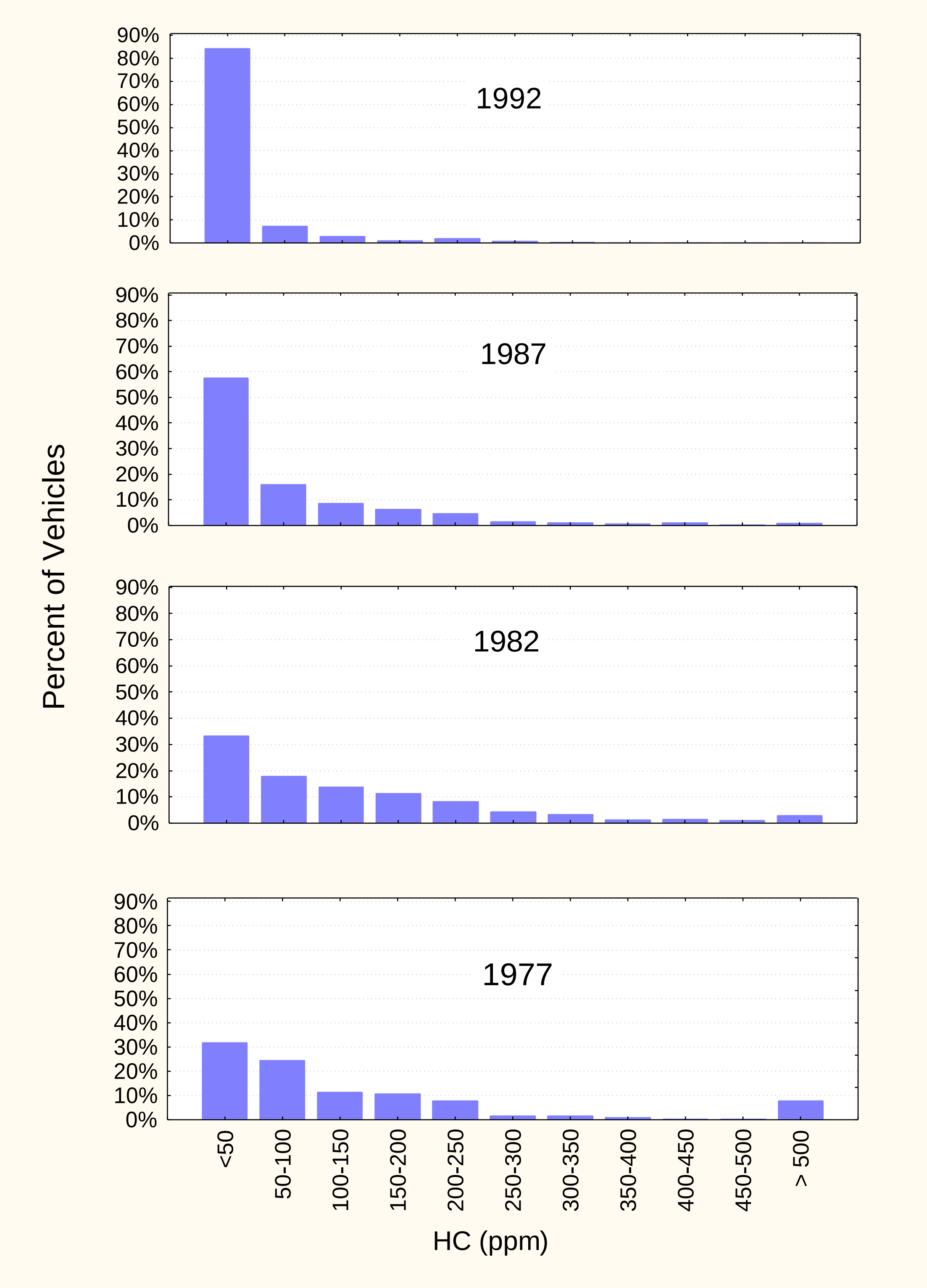


Figure 5. Distribution of HC Emissions for Four Different Model Years

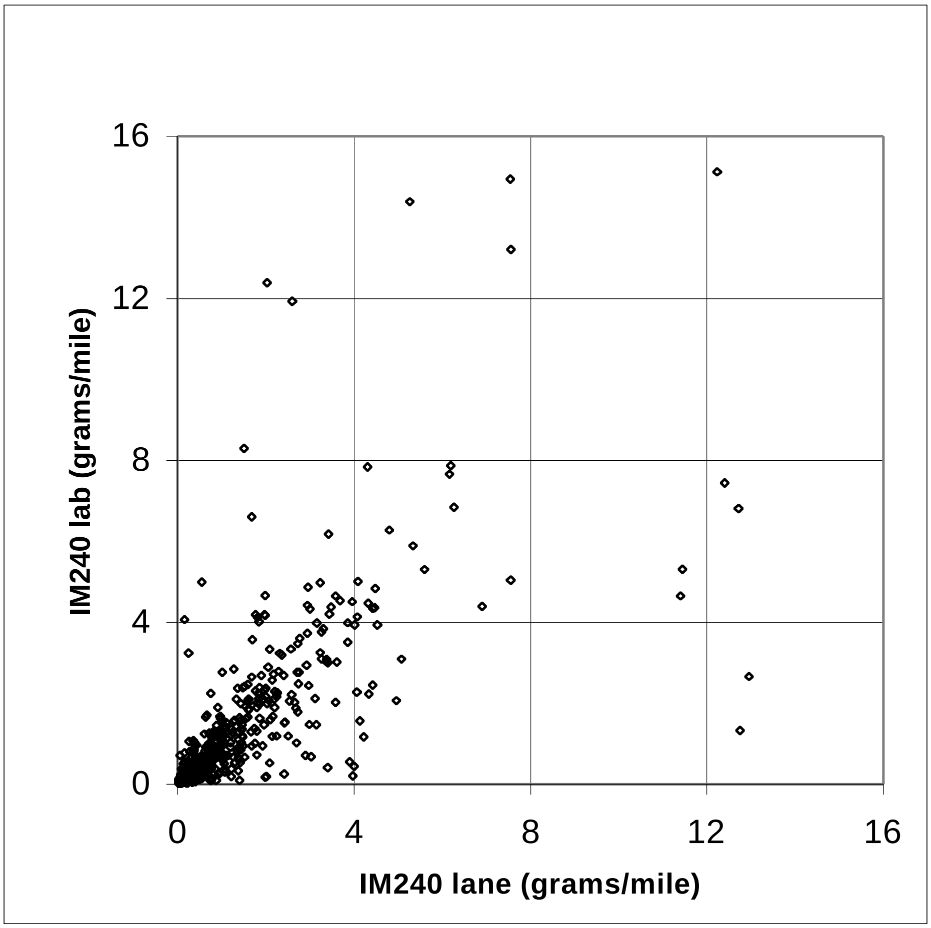


7. Emissions of Individual Vehicles Vary from Test to Test

Observers often assume an emissions test measures the "true" emissions of a vehicle. However, many vehicles, particularly higher emitting vehicles, exhibit variability from moment to moment and from day to day, so that no single measurement necessarily represents the "true" emissions level for an individual vehicle. Test to test variability is often observed for vehicles given multiple emissions tests.[7]

Figure 6 displays the results of multiple IM240 testing of several hundred vehicles. These data were collected by USEPA in Indiana in the early 1990s. Each car was first tested at an I/M lane and then tested at a USEPA-contracted lab within a few days after the first test. If the emissions of each vehicle were the same on each test, then all of the points would fall along a diagonal line from the lower left to the upper right. Spreading of the points indicates variability between the results of repeated tests. The spread in the points indicates that the emissions of these vehicles often changed quite a bit from test to test.

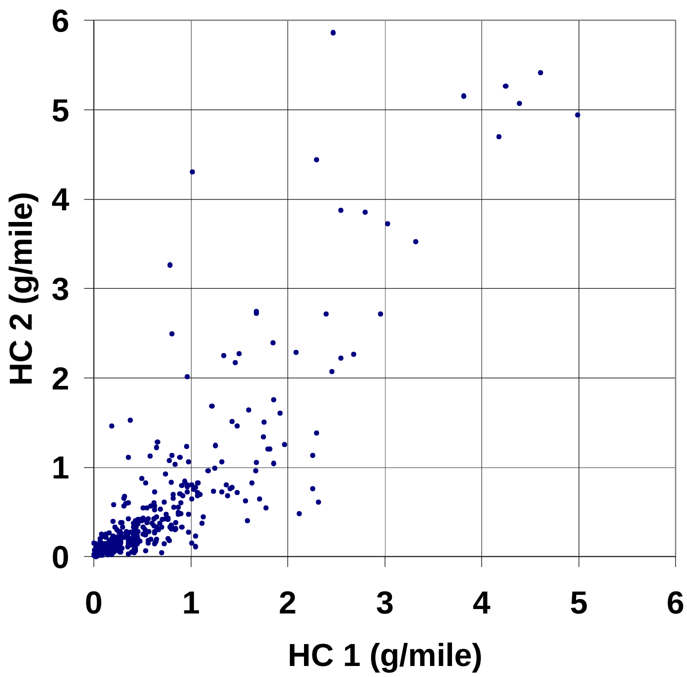
Figure 6. HC Emissions of Cars Tested Twice on the IM240 Test

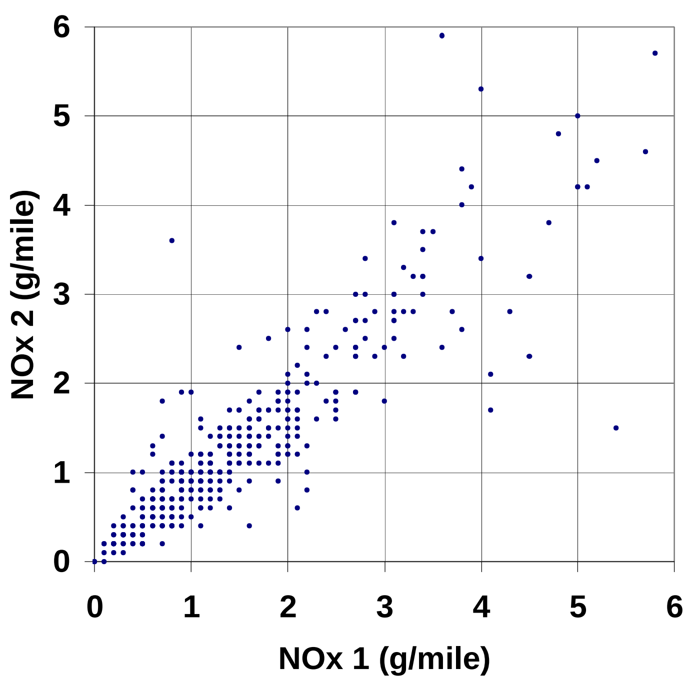


[7] Bishop, G. A., et. al (1996) "Motor Vehicle Emission Variability", *Journal of the Air and Waste Management Association*, vol. 46, pp. 667-675, July 1996.

Figure 7 displays HC and NOx data from back-to-back IM240 tests in Illinois in early 1999. Once again, a significant amount of variability can be seen between tests on the same cars.

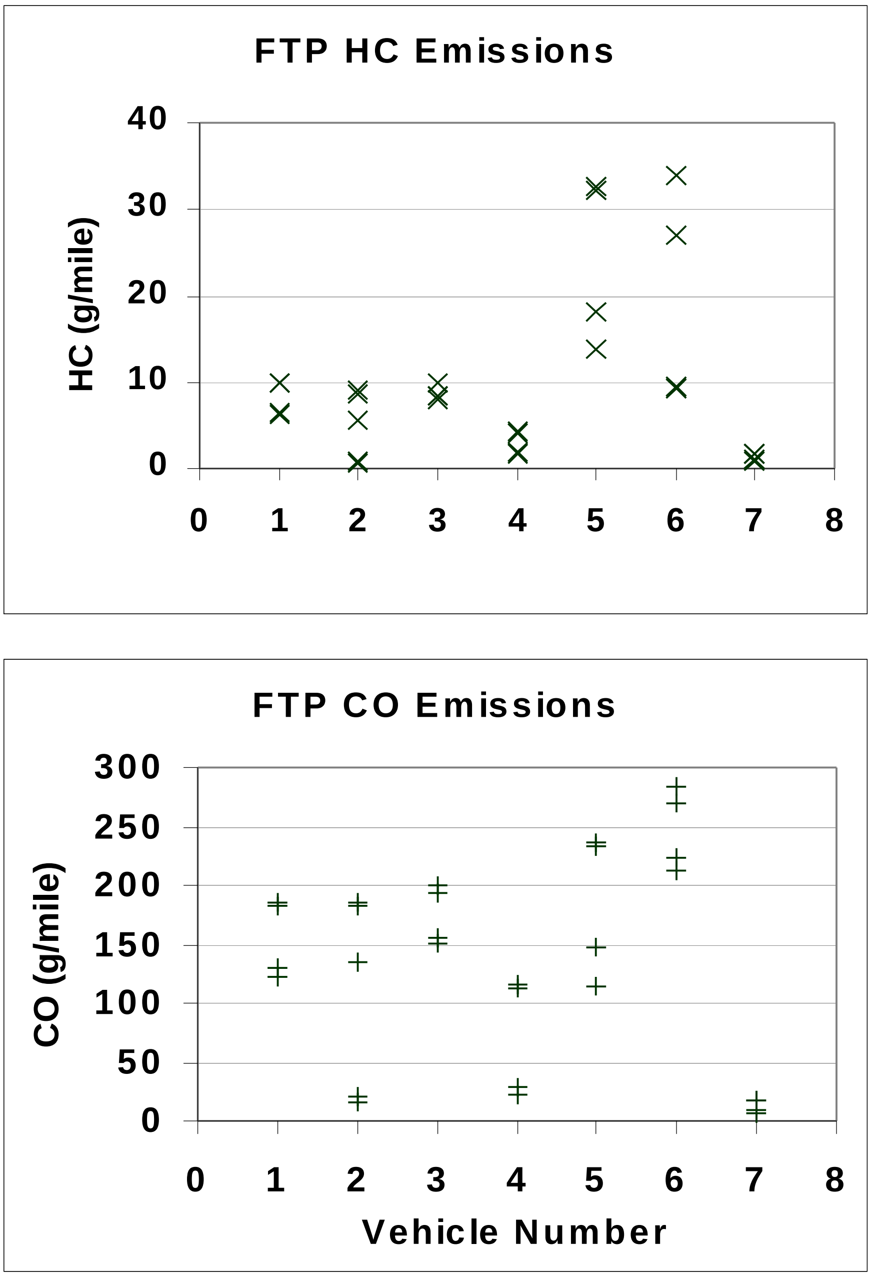
Figure 7. Results of Back-to-Back IM240 Tests in Illinois





Finally, Figure 8 displays results of multiple FTP tests on seven cars selected because they were high emitters. Each number along the horizontal axis represents one vehicle. The "×" and "+" markers denote emissions results on each individual FTP test for each car. As the charts show, emissions varied by large amounts from test to test for these vehicles.

Figure 8. HC and CO Emissions on Multiple FTP Tests of Seven High Emitting Vehicles



Source: Knepper, J. C., et al. (1993). "Fuel Effects in Auto/Oil High Emitting Vehicles", Society of Automotive Engineers, paper #930137.

The FTP tests vehicles on a dynamometer over a range of speeds and accelerations. Test conditions are carefully controlled in order to minimize factors that could cause emissions variability. In the regulatory community, the FTP is considered the “gold standard” for measurement of vehicle emissions. Nevertheless, vehicles can display significant variability on the FTP.

Vehicles that are low emitters on average have low emissions almost all of the time and average high emitters have high emissions almost all of the time. Nevertheless, these three data sets show that many vehicles exhibit a great deal of random variation from test to test.

This variability can have a significant effect on pass/fail decisions when applying I/M cut points. In the Illinois data above, if one applies USEPA’s phase-in cut points for the IM240 test and treats the second test as a check on the first, one would find that 20 percent of cars that failed the first test, passed the second test. On the other hand, 26 percent of cars that should have failed the first test actually passed. These jumps between passing and failing are more likely to happen to cars with average emissions that are relatively close to the failure cut points because emissions variations of just a few percent from test to test can change the pass/fail determination. Pass/fail changes can also occur between tests for high emitting vehicles that have intermittent malfunctions.

8. Total Emissions Are Dominated by a Small Number of High Emitters

As noted earlier, most cars have relatively low emissions, and a few cars have very high emissions. Because of this skewed emissions distribution, a small number of high-emitting vehicles account for most of the emissions from the fleet. This result can be seen by ranking cars from dirtiest to cleanest and then determining what percentage of total emissions comes from a given percentage of the fleet.

Figure 9 was created by ranking cars from dirtiest to cleanest and then dividing them into ten groups or “deciles”, with the first decile representing the cleanest 10 percent of cars and the tenth decile representing the dirtiest 10 percent of cars. Figure 9 shows that the dirtiest 10 percent of cars for a given pollutant account for anywhere from 30 percent to almost 50 percent of total emissions of that pollutant. The cleanest 50 percent of cars account for about 10 to 15 percent of total emissions.[8]

The dirtiest ten percent of cars on one pollutant might not be the same cars that are the dirtiest for another pollutant, though there will be some overlap. To see this result, one can first add together the pollutants and then rank them. Figure 10 shows the results for HC and NOx. For this chart, HC and NOx emissions of each vehicle were added together and then the vehicles were ranked from dirtiest to cleanest, just as before. As the graph shows, the dirtiest 10 percent account for about 37 percent of total HC+NOx. So even when combining pollutants, one observes a skewed emissions distribution.

[8] Once again Roadside ASM data were converted to FTP equivalents and then emissions were weighted by the estimated travel fraction for each model year.

Figure 9. Distribution of HC, NOx and CO Emissions in the Vehicle Fleet (separate ranking for each pollutant)

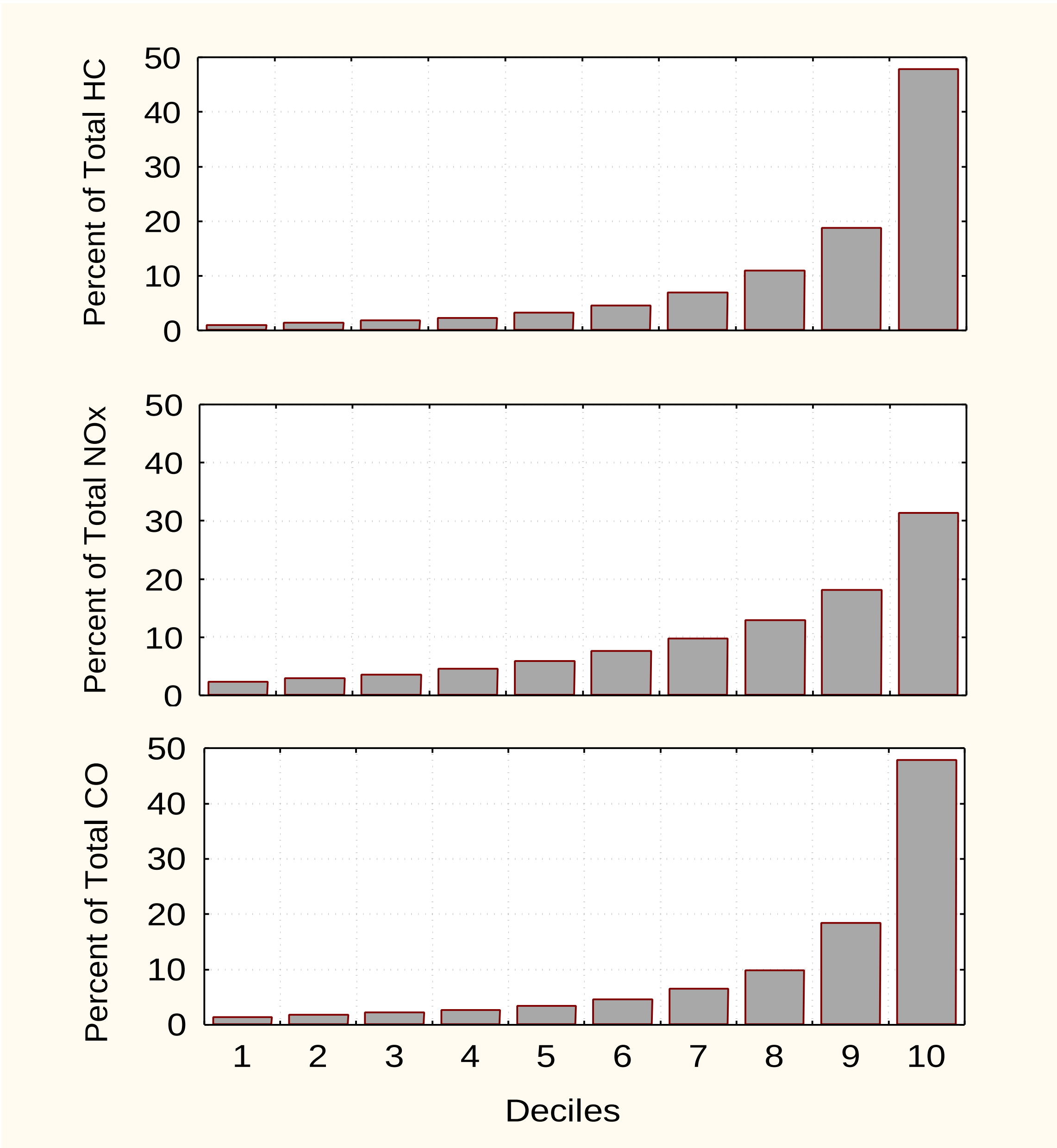
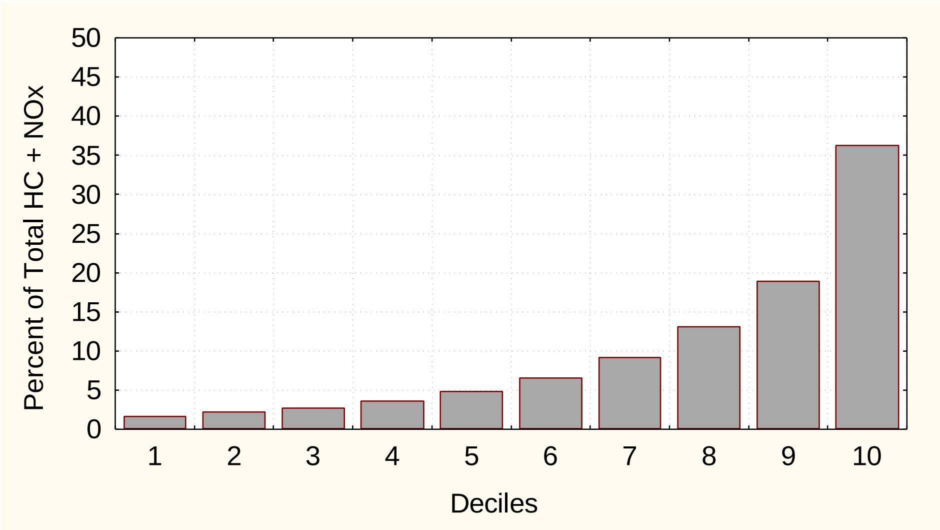


Figure 10. Distribution of HC+NOx Emissions in the Vehicle Fleet



9. Most Potential Smog Check Emissions Reductions Come from a Small Percentage of Vehicles

The above discussion looked at the distribution of *total* emissions. However, the key question for Smog Check policy is the amount and distribution of *reducible* emissions. If most of the reducible emissions reside among a small number of vehicles, this would have different policy implications than if the reducible emissions were spread out over many vehicles.

In order to determine which emissions are reducible and which are not, one must define standards above which emissions are considered to be “excess” or “repairable”. Setting these standards is an inexact science for at least two reasons. First, only imperfect information is available on the extent to which various vehicles can be diagnosed and repaired within reasonable cost and time constraints. Second, the success of a repair effort will depend on the conditions under which the vehicle is repaired. For example, in a research study with well-trained mechanics, repairs might be more effective than in a real-world situation with average mechanics and motorists who wish to keep costs down. Third, vehicles exhibit intrinsic emissions variability. This means that if retested, some vehicles that failed would pass and some that passed would fail.

For the purposes of this analysis, the IMRC has chosen to use the most stringent standards that USEPA and ARB employ when they develop failure cut points for I/M programs. These failure standards then become the arbiter of what is an excess emission. Emissions over and above these standards are considered to be potential benefits of the Smog Check program. To find out how these potential benefits are distributed among vehicles, the analysis proceeds as follows:

- Using the random roadside ASM data, convert emissions to FTP equivalents using the ERG equation. The IMRC used the Roadside ASM data collected between February 1997 and June 1998 in this case.
- Calculate excess emissions based on FTP failure cut points.[9]
- Weight emissions by the percent of the vehicle fleet in each model year and the average annual miles traveled by each model year.[10]
- Rank cars from dirtiest to cleanest based on the sum of their excess HC and NOx emissions and divide them into ten deciles from dirtiest 10 percent to cleanest 10 percent.

Figure 11 shows the result of this analysis. As the figure shows, about 73 percent of potential HC+NOx reductions come from the dirtiest 10 percent of the vehicles. Ninety-three percent come from the dirtiest 20 percent of vehicles. But 36 percent of vehicles fail the test for HC or NOx. Thus, more than 90 percent of potential HC and NOx benefits come from about 55 percent of the vehicles that fail the test.[11]

One might also look at the distribution of excess HC, NOx, and CO emissions separately. To do this one can rank cars based on their excess emissions of the pollutant in question and divide into deciles just as before. Doing this for each pollutant separately, one finds that the cars in the highest 10 percent for HC, NOx, and CO emissions account for, 79, 93, and 88 percent of potential HC, NOx, and CO benefits, respectively. Table 4 displays these results.[12]

Table 4. Percent of Excess Emissions in Dirtiest 10% of Fleet (Separate Ranking for Each Pollutant)

Pollutant	Percent
HC	79%
NOx	93%
CO	90%

[9] ARB recommends cut points that are generally twice the FTP certification standard for vehicles back to the 1975 model year, and somewhat lower than this for pre-1975 vehicles.

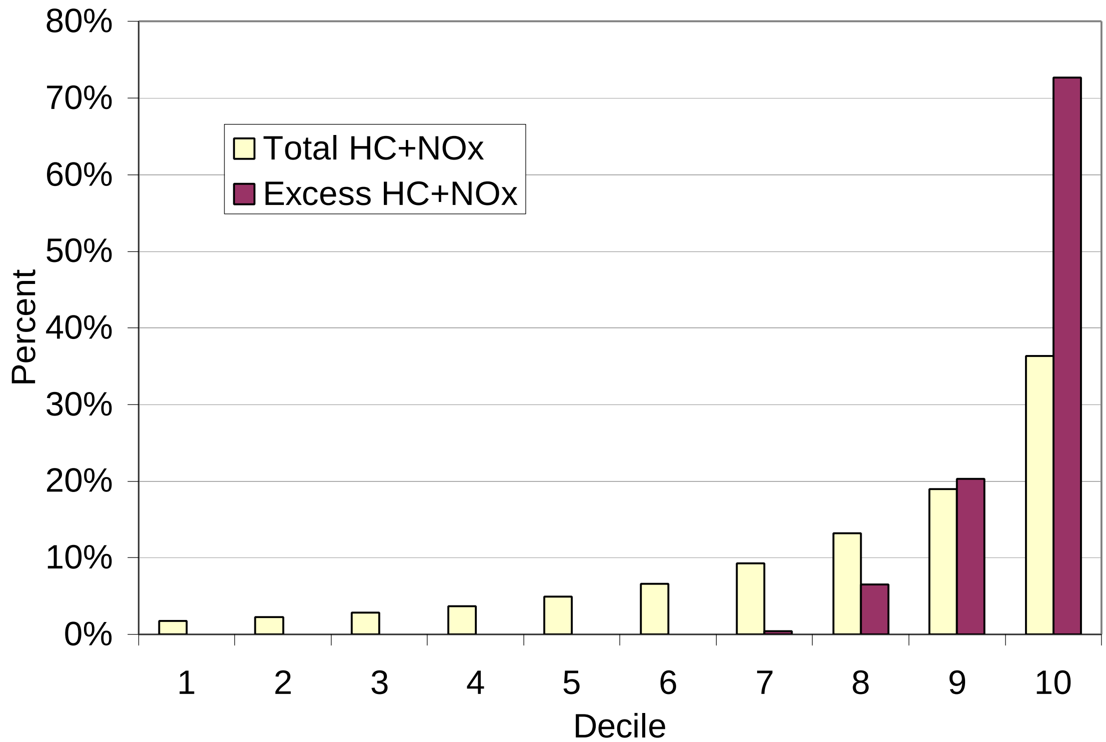
[10] Since this calculation is based on roadside data collected between February 1997 and June 1998, the BAR Travel Fraction Calculator for September 1997 was used estimate the fleet model year distribution and annual miles traveled by model year.

[11] Derive this as follows: 36.3% of cars fail for HC or NOx in this scenario. Of these, 20% account for 93% of HC+NOx excess emissions. 20/36.3 = 0.55 = 55%.

[12] Remember, however, that this analysis excludes non-tailpipe HC emissions, which are unknown. Some vehicles with high non-tailpipe HC emissions would be included in the worst 10 percent of vehicles for each pollutant, but some would not.

Excess emissions are much more skewed than total emissions because most cars have no excess emissions (that is, most cars don't fail the emissions test because they are relatively clean). Likewise, excess NOx and CO are more skewed than excess HC because fewer cars fail the test for NOx and CO (in this case 16% for NOx and 19% for CO vs. 32% for HC).[13]

Figure 11. Distribution of Total and Excess HC+NOx Based on Roadside ASM Data Converted to FTP Equivalents



These results are typical of what one sees in all vehicle fleet-emissions measurements. For example, figures 12 and 13 show the distribution of total and excess HC+NOx emissions from vehicles in Sacramento in 1994 and in Phoenix in 1998. In both cases, vehicles were tested on the IM240 test, and USEPA's final IM240 cut points (the most stringent cut points USEPA recommended states use in their I/M programs) were used as the arbiter of what emissions are excess emissions. Once again, one sees that about 75 percent of potential combined HC and NOx benefits come from 10 percent of the vehicles. One also sees the similar results as before when looking at each pollutant separately. For example, in the Sacramento data, 85 percent of potential HC benefits and 92 percent of potential NOx benefits come from the dirtiest 10 percent of vehicles for the respective pollutants.

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[13] The recommended ARB FTP HC cut points are likely too stringent for older vehicles. For example, the cut point for 1977-84 passenger cars is 0.82 g/mile. Although cars of this vintage were initially certified at half this level, many of them would not be able to meet this level now (see below for more on repair issues). If more realistic cut points were used, fewer cars would fail for HC and potential HC benefits would be even more skewed toward the dirtiest 10 percent.

The cut points used for these analyses are the most stringent that anyone has considered implementing in an I/M program. Using these cut points makes this analysis conservative. The reason for this is that the potential benefits of Smog Check become more skewed towards fewer vehicles as one uses less stringent cut points (i.e., as one fails fewer vehicles on the emissions test).

Figure 12. Distribution of Total and Excess HC+NOx Based on IM240 Testing in Sacramento in 1994

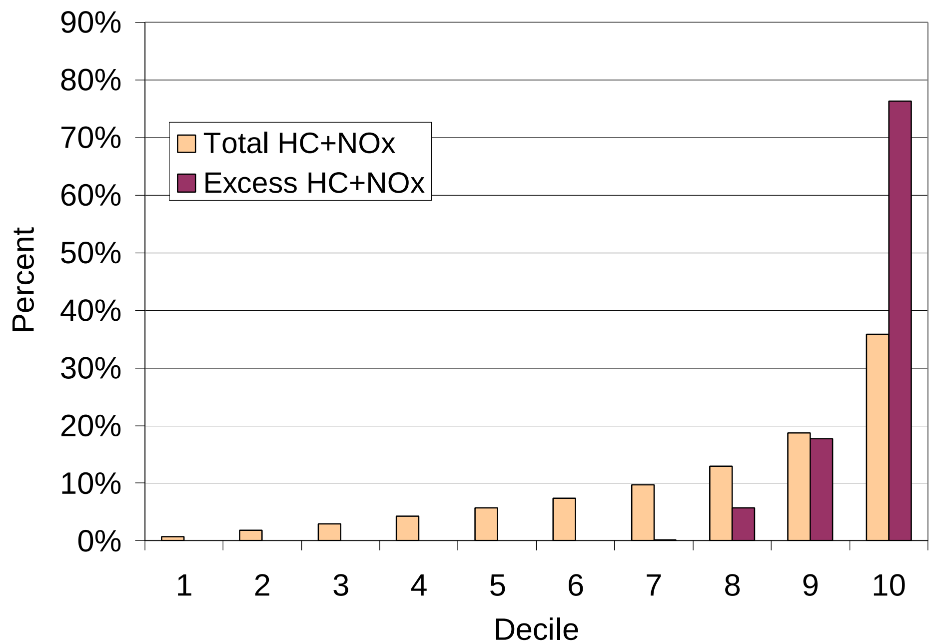
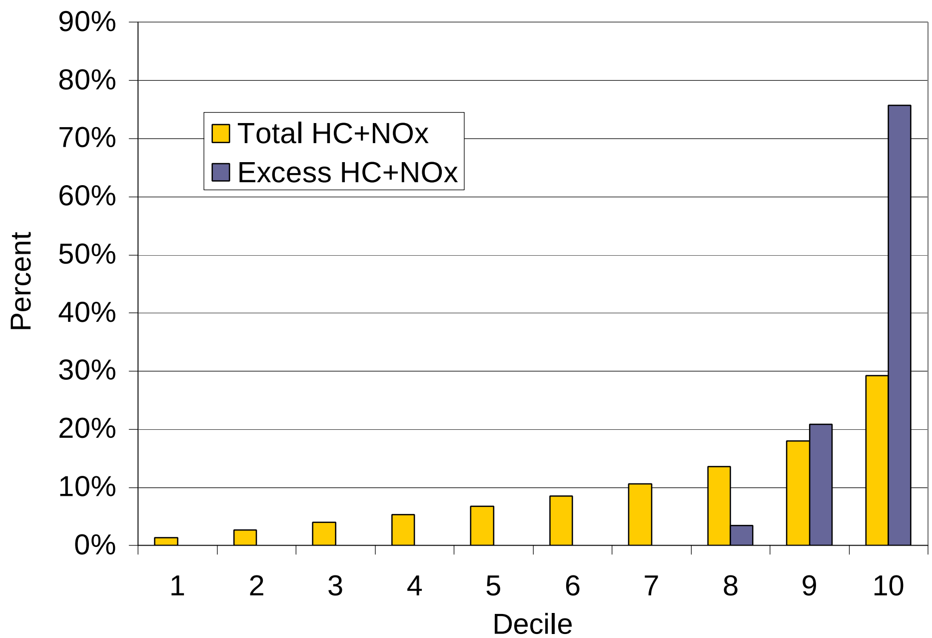


Figure 13. Distribution of Total and Excess HC+NOx Emissions Among Vehicles Based on IM240 Testing in Arizona in 1998



The charts above show how *potential* benefits are distributed in the fleet. But to derive these charts, this initial analysis did not use actual repair data, but merely *assumed* that all of the vehicles could actually be repaired below the relatively stringent IM240 and FTP cut points. However, this assumption does not appear to mirror actual experience. Some vehicles are difficult to repair, and, in some cases, attempting to fix a car for one pollutant can cause emissions of other pollutants to climb after repair. Actual vehicle repair studies can thus give a more realistic view of (1) what portion of *potential* benefits can actually be realized in practice, and (2) what percent of failing vehicles must be repaired to achieve these benefits.

In 1994, the Sunoco Corporation funded a study in Pennsylvania in which owners of high-emitting cars identified by remote sensing would be offered free repairs in exchange for participating in the program. Mechanics who repaired cars in the study were given special diagnostic and repair training before the study began and were able to consult with trainers while they repaired vehicles. Although the program achieved substantial emissions reductions (67, 74 and 31 percent for HC, CO and NOx, respectively) as measured by IM240 testing, less than 40 percent of vehicles met USEPA's final IM240 cut points after one round of repairs with a cost limit of $450. Seventy-five percent of pre-1985 cars did not meet the IM240 standards after repair. The mechanics who repaired the cars had only an idle test as a diagnostic tool, and had not had previous experience repairing cars to pass an IM240 test. Nevertheless, this study suggests that some cars may be difficult to repair to stringent standards.

The 1995 El Monte Pilot study in California attempted to determine how effective mechanics could be in repairing cars using the IM240 or ASM tests as the emissions test. Repairs were performed by expert mechanics hired by ARB for the study. 193 vehicles were initially selected for the study because they failed either the IM240 or ASM test when brought in to ARB. Of the 193 vehicles, 61 percent were repaired within the $600 cost limit, 19 percent exceeded the cost limit, and 20 percent passed the pre-repair emissions test at the repair facility and were therefore not repaired. All cars were given an FTP test before and after repairs were completed. Ninety percent of total HC, NOx, and CO emissions reductions came from only 40 percent of the vehicles in the study. That is, repairing 40 percent of vehicles that failed the emissions test accounted for 90 percent of the emissions reductions achieved.[14]

If one assumes that (1) the vehicles in the El Monte study were representative of failing vehicles in general at the time, and (2) 30 percent of the vehicle fleet would have failed the test at the relatively stringent cut points used in the El Monte study (which is roughly the failure rate for the vehicles in the 1994 Sacramento data described above), then for the fleet as a whole (i.e., both failing and passing vehicles), 90 percent of total

[14] Lawson, D. (1998) "The El Monte Pilot Study – A Government-Run I/M Program," Paper presented at the 8th CRC On-Road Vehicle Emissions Workshop, San Diego, California, April 21, 1998.

repair benefits came from 12 percent of the entire vehicle fleet.[15] Other repair studies also show that a minority of failing vehicles accounts for the vast majority of repair benefits.[16]

Not only does attempting to repair cars with marginally high emissions create few emissions benefits, it can also be counterproductive. For example, in the El Monte study, some cars with relatively low initial FTP emissions had higher FTP emissions for at least one pollutant after repair. Twelve percent of repaired cars had higher FTP emissions overall after repair.[17] Other repair studies have also found few emissions benefits from repairing marginally failing cars.[18]

The El Monte study also highlights the issue of emissions variability, which was discussed in Section 7. Twenty percent of the vehicles that were selected for the program because they failed the emissions test when brought to ARB, passed a second test at the repair facility. Furthermore, when these vehicles were brought back to ARB and retested, 56 percent failed for at least one *different* pollutant than they had failed for in their first test at ARB.[19] These vehicles had average emissions 50 to 70 percent lower (depending on the pollutant) than the vehicles that were repaired. That is, the vehicles that jumped between failing and passing status from one test to the next, had emissions much closer to the failure cut points than vehicles that continued to fail on successive tests (prior to repair).

10. Current Failure Cut Points Capture Most Potential Benefits

Current Smog Check failure cut points are less stringent than the failure cut points ARB used to derive California's SIP emissions reduction targets. For example, based on the roadside data, 23 percent of all model year 1974 to 1999 vehicles on the road would fail Smog Check at current cut points, but 37 percent would fail at the ARB SIP cut points.[20] Section 9 demonstrated that when applying the most stringent cut points ARB and USEPA have considered using in an I/M program, the dirtiest 10 percent of vehicles

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[15] Note that the second assumption is conservative. At a lower failure rate, 90 percent of the benefits would reside in a *smaller* percent of the vehicle fleet.

[16] Slott, R. (1993) "Economic Incentives and Inspection and Maintenance Programs," Proceedings of the AWMA Specialty Conference *New Partnerships: Economic Incentives for Environmental Management*, November 3, 1993.

[17] With benefits calculated as HC+CO/7+NOx for each car.

[18] Slott, R. (1993), ibid

[19] Lawson, D. (1996) "Analysis of the 1995 El Monte I/M Pilot Study Data Set", paper Presented at the 6th CRC On-Road Emissions Workshop, March 18-20, 1996.

[20] The on-road failure rate at current cut points is 23% for all 1974-1999 vehicles. (This rate rises to 29% when only change-of-ownership testing is assumed for vehicles four-years-old and newer, because including fewer new vehicles increases the average failure rate for the remaining vehicles. At the ARB SIP cut points, the on-road failure rate rises from 38% to 46% when only change-of-ownership testing is assumed for the four newest model years). However, the failure rate at Smog Check stations is only about 14%. The discrepancy between the roadside data and the official Smog Check results is likely due to a combination of factors, including (1) deterioration of vehicles' emissions systems since their last Smog Check, (2) vehicles that passed their last Smog Check, but should not have, (3) unregistered vehicles that never received a Smog Check and are probably more likely than the average car to be a high emitter, and (4) cars that received repairs or maintenance shortly before their initial Smog Check or official pretest. Part III of this report provides estimates for some of these factors.

for each pollutant includes from 80 to more than 90 percent of potential I/M benefits. Furthermore, actual repair studies have found that repairing less than half of the vehicles that fail the test accounts for 90 percent of repair benefits. Given these results, a central issue to evaluate is where the current Smog Check cut points fall in relation to vehicle emissions. For example, are there still more repair benefits to be had by failing more cars, or do current cut points capture a substantial majority of potential benefits?

Table 5 displays the percent of the fleet that would fail the ASM test at current cut points.[21] Note that current cut points would fail more than half the vehicles that would fail using the ARB SIP cut points. In addition, more than 10 percent of vehicles fail for HC and CO and 9 percent fail for NOx, suggesting that the vehicles that would account for most potential Smog Check benefits should be captured at existing cut points. This can be confirmed by taking a closer look at the emissions distribution of vehicles based on the roadside ASM data.

Table 5. On-Road Failure Rate (Emissions Test Only) by Pollutant Using Phase 4 Cut Points

Pollutant	Failure Rate
HC	14%
CO	12%
NOx	9%
Overall	23%

Figures 14a, 14b, and 14c display the distribution of HC, NOx and CO emissions, respectively, of 1984-86 vehicles. Because this is an older subset of the fleet, one should expect a greater percentage of these vehicles to be high emitters than would be found in the fleet as a whole. Each graph shows the roadside ASM 2525 test data for 1984-86 passenger cars, which have been ranked and plotted from dirtiest to cleanest (each graph represents the results of a separate ranking for each pollutant). Each dash in the graph represents a single vehicle. The dashes mesh together to give the appearance of a line at lower emissions levels.[22] Two horizontal lines show the location of the current median cut point (upper line) and the median ARB SIP cut point (lower line).[23] Vehicles with

[21] The data for this section are the roadside data collected from January 1, 1998 onward, excluding cars that had already had an Enhanced test before the roadside measurement. The fleet model year distribution is the November 1998 estimate from BAR’s Travel Fraction Calculator.

[22] There are a few cars with HC emissions even greater than 2000 ppm (about 7000 ppm for the highest emitter). The scale stops at 2000 ppm for easier viewing of the lower emissions levels.

[23] BAR and ARB set cut points by dividing vehicles into categories based on technology and whether the vehicle is classified as a passenger car or a truck. Cut points also vary to some extent within categories as well based on vehicle weight. The category of 1984-86 model year passenger cars was used for illustration because these vehicles account for much of the emissions reduction benefit of Smog Check II (see Part III of this report for emissions reduction estimates), but the results apply to the fleet as a whole as well.

emissions above the line would fail the emissions test at the respective cut points. The graphs in Figure 14 illustrate the following key points:

- Current Smog Check cut points appear to be capture all of the high emitters for HC and CO. The additional cars failed by the ARB SIP cut points would provide few additional emissions benefits.
- Current cut points also appear to capture most of the NOx high emitters. However, the NOx situation is less clear cut because the NOx curve falls less steeply than those for HC and CO and there is a larger difference between the current and ARB SIP cut points.

The overall fleet failure rates and the emissions distributions in the roadside data suggest that current cut points are stringent enough to capture the cars from which most of the emissions benefits could be achieved. However, additional analysis of data from roadside measurements, official Smog Checks and previous repair studies would provide more detailed information on the actual repair benefits achievable from cars with different emissions levels. The IMRC plans to perform this analysis in the coming months.

Figure 14a. Distribution of HC Emissions and Repair Benefits for 1984-86 Passenger Cars

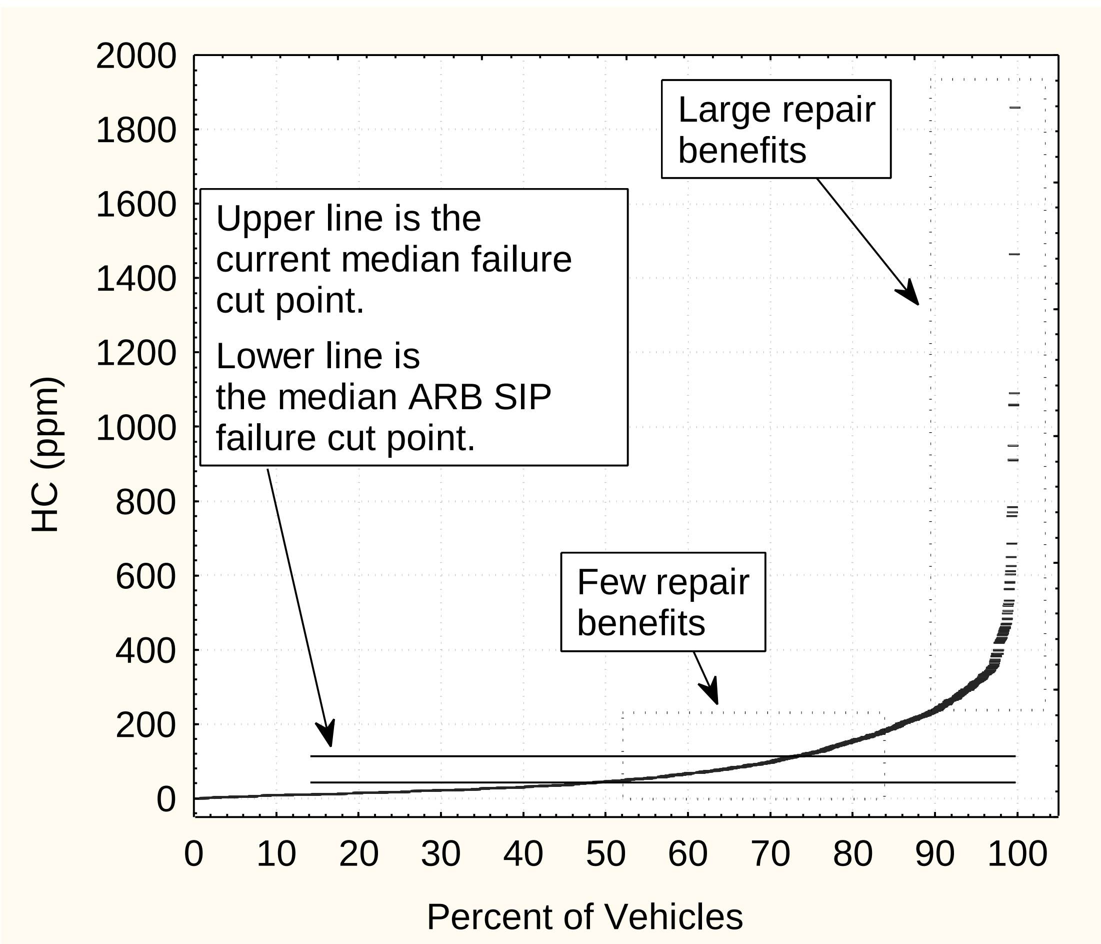


Figure 14b. Distribution of NOx Emissions and Repair Benefits for 1984-86 Passenger Cars

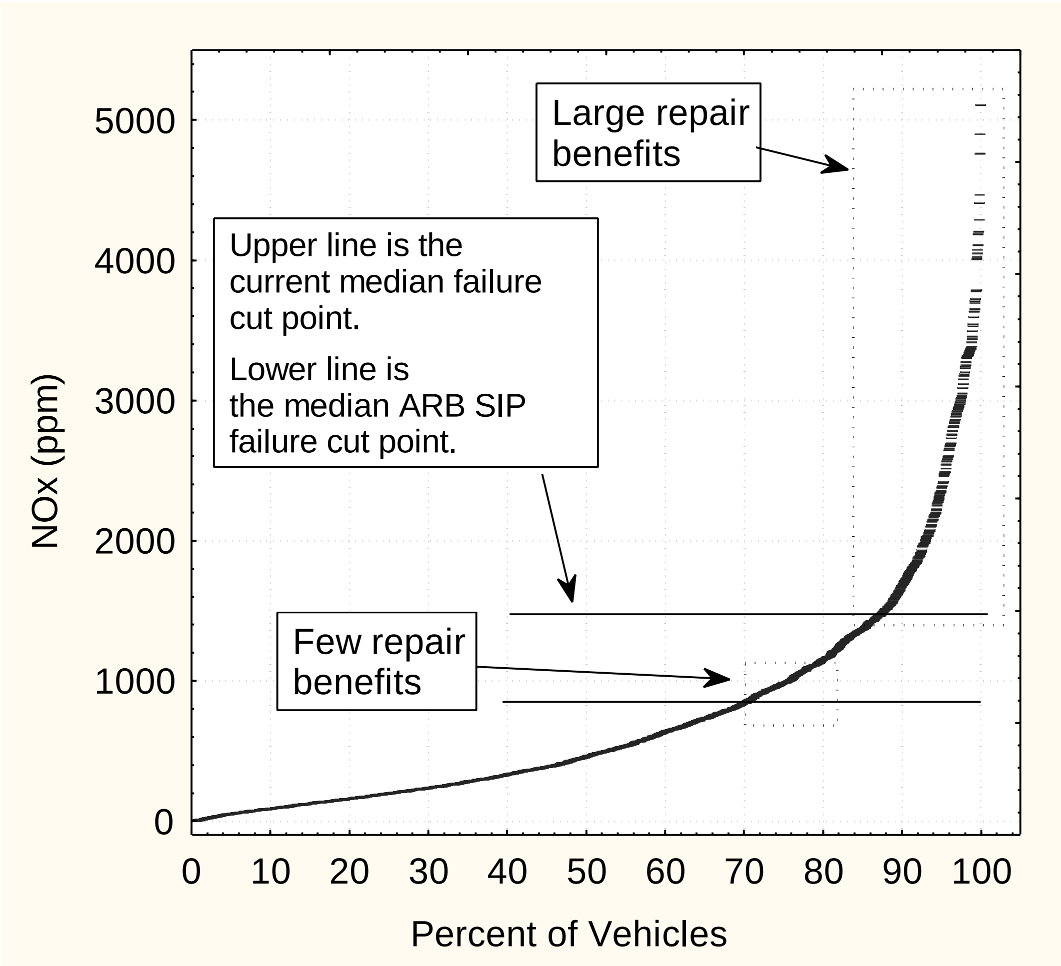
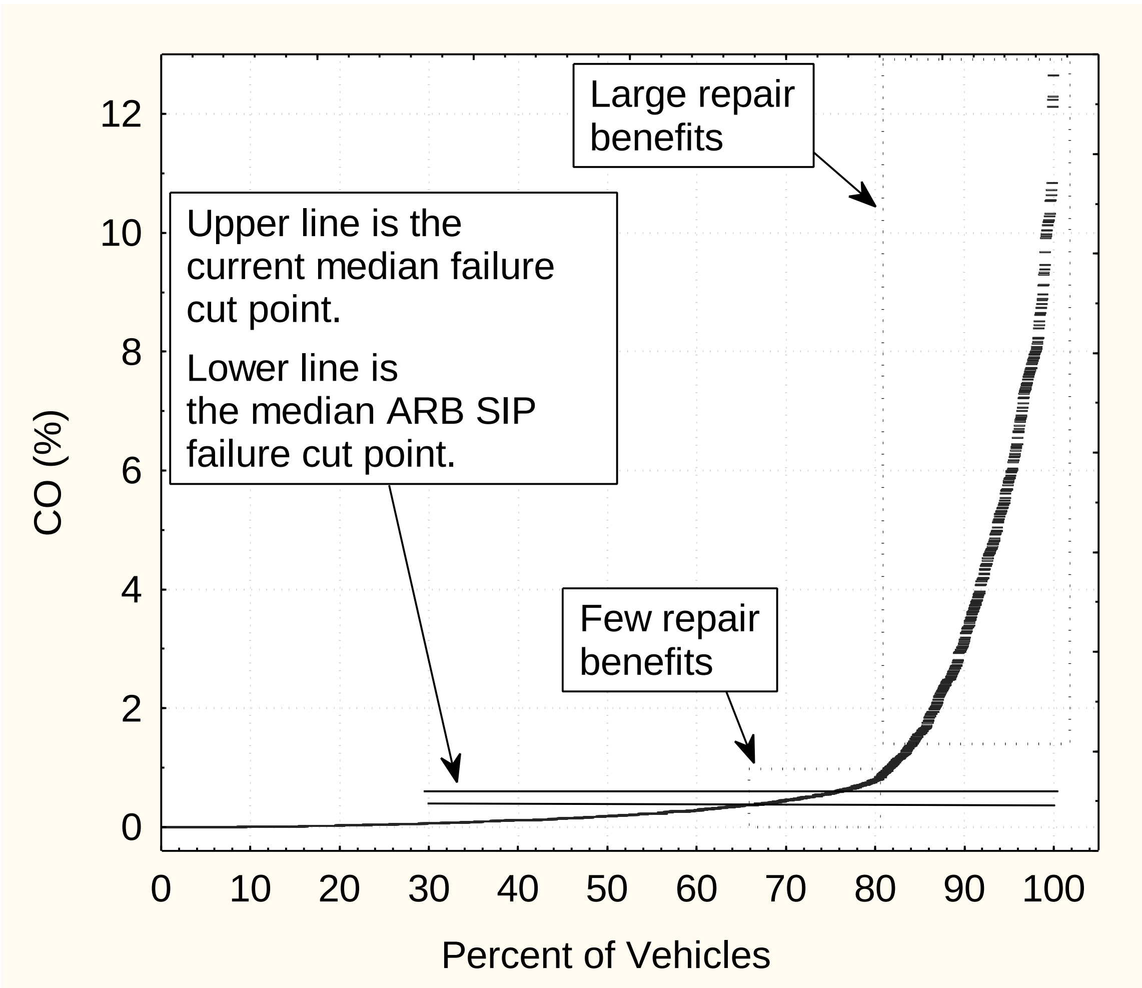


Figure 14c. Distribution of CO Emissions and Repair Benefits for 1984-86 Passenger Cars



11. Failure Cut Points Used for SIP Emissions Reduction Targets Would Fail Many Cars with Only Marginally High Emissions

The graphs in Figure 14 show that the cars that fail at current cut points would provide significantly more emissions reductions than the *additional* cars that fail at the ARB SIP cut points. For example, if cars that fail at the current cut points are repaired down to the ARB SIP cut points, they would achieve average emission reductions of about 220 ppm for HC, 3.3 percent for CO and 890 ppm for NOx.[24] The corresponding emissions reductions for cars falling between the two sets of cut points are about 12 ppm for HC, 0.15 percent for CO, and 280 ppm for NOx. Thus, when compared with the additional cars failed by the ARB SIP cut points, the cars that fail under current cut points would achieve emissions reductions 18 times greater for HC, 22 times greater for CO and three times greater for NOx. In addition, based on results of previous repair studies, the actual emissions benefit for these lower-emitting cars might be less than this because some of these cars would likely be difficult to repair or might even have increases in one or more pollutants after repair (see Section 9, above).

The three graphs in Figure 14 illustrate an additional potential problem with very stringent cut points that is related to emissions variability. Section 7 showed that many vehicles have intrinsically variable emissions and change to some extent from test to test. This means that some cars that fail a test will pass if tested again without any repairs having been made, and vice versa. This “false failure” and “false pass” problem will likely be more pronounced if there are more vehicles with emissions relatively close to the cut points. To the extent that the cut points are set so that they cross the emissions curve when its slope is steep (the right side of the graphs where the high emitters are), there will be fewer cars with emissions close to the cut point. On the other hand, to the extent that the cut points cross the emissions curve where its slope is shallow (both sets of cut points for HC exhibit this characteristic, for example), many more cars will have emissions near the cut points.

In addition to limitations on their potential to create additional Smog Check benefits, the ARB SIP cut points would fail a very high percentage of older vehicles. Figure 15 displays the average emissions test failure rates (i.e., total failure rate including all three pollutants and both the ASM 2525 and ASM 5015 tests) by model year of vehicles measured by Roadside ASM using current and ARB SIP cut points. Roughly 90 percent of pre-1984 vehicles would fail the test at the SIP standards, and 38 percent of all 1974 to 1999 model year vehicles would fail.[25]

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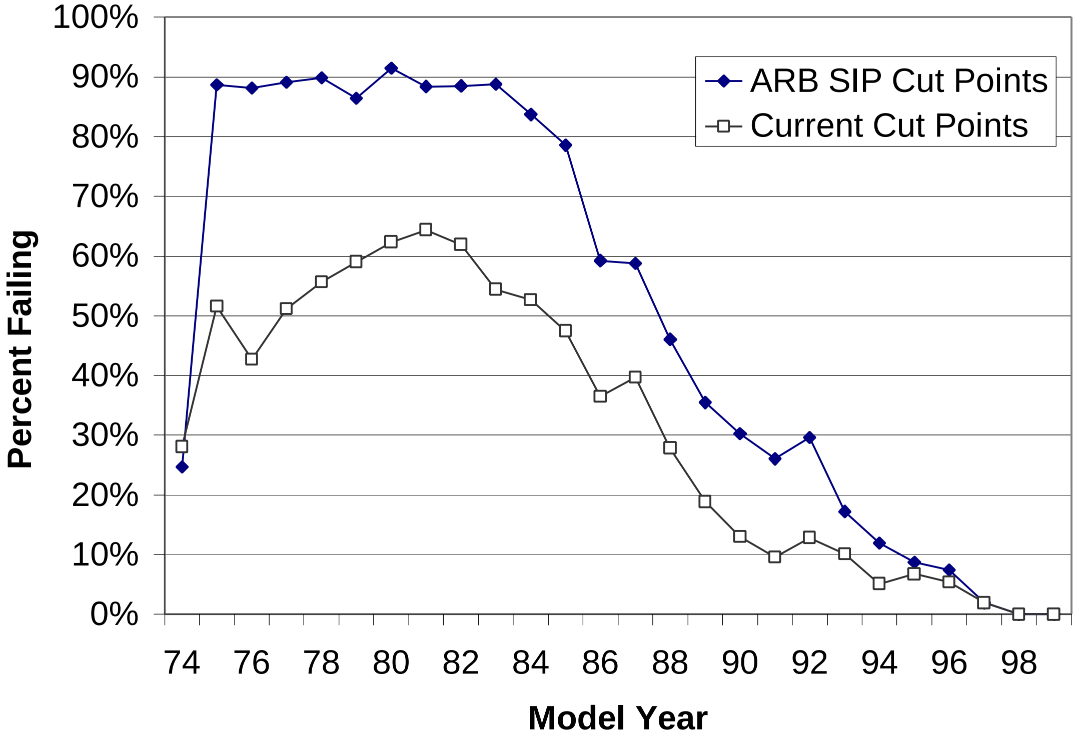
[24] One might argue that at current cut points, cars would not be repaired down to the ARB SIP cut points. However, analysis of the VID data indicates that, on average, final emissions of fail-pass vehicles are well below the current cut points. In addition, as discussed below, cut points for initial failure and post-repair verification need not be the same.

[25] If only change-of-ownership testing is assumed for vehicles four years old and newer, the failure rate for the remaining vehicles rises to 46 percent (see footnote #20).

Figure 15. Overall Emissions Test Failure Rates by Model Year Using Current and ARB SIP Failure Cut Points Applied to Roadside ASM Data



12. Appropriate Cut Points for Initial Failure and Post-Repair Certification Might Be Different

Failure cut points serve two purposes. They (1) identify the vehicles in need of repair under the Smog Check program, and (2) verify that a vehicle has been repaired and its emissions reduced. Although I/M programs have always used one set of cut points for both purposes, these are actually two different functions. So far, this analysis has focused on cut points for initially identifying the cars that are candidates for repair. It was found that current cut points fail many marginal emitters for HC and that the ARB SIP cut points would fail many marginal emitters for HC and CO and some for NOx as well. On the other hand, it may be that current cut points are not sufficiently stringent to ensure proper repair of some vehicles. It is possible that I/M programs could be more efficient at both identifying appropriate cars for repair and ensuring proper repair by having separate cut points for initial failure and post-repair verification of low emissions. This issue should be investigated further.